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2813

TESTING OF MOTOR VEHICLE HEADLIGHTING DEVICES

AND

INVESTIGATION OF CERTAIN PHASES OF THE HEADLIGHT GLARE PROBLEM

BY

C. R. GRANBERRY

ENGINEERING RESEARCH SERIES NO. 24
Bureau of Engineering Research
Division of the Conservation and Development of the Natural Resources of Texas

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

FOREWORD

Mr. C. R. Granberry, the author of this bulletin, has for several years been interested in the problem of automobile headlighting. He had an important part in advising the Thirty-ninth Legislature concerning the writing of the Texas Headlight Law.

As the first Headlight Engineer after the passage of this law, he supervised the establishment of the various headlight test stations all over the State and also gave much assistance to the Photometric Laboratory in the testing of headlight devices. For the past two years, as Instructor in Electrical Engineering, he has taken an active part in the research work in the Photometric Laboratory.

DIRECTOR OF THE BUREAU.

SCOPE OF BULLETIN

This bulletin is issued by the Bureau of Engineering Research of the University of Texas to show the nature of the routine and research work carried on in the Photometric Laboratory. During the past two years most of the routine work has been that of testing various types of automobile headlight equipment for the Texas State Highway Department. These tests are made on each type and size of device submitted to that Department for approval. The results of these tests and certain information regarding the general question of automobile headlighting progress are included here.

The research work has been along the lines of determining and predicting road visibility under various degrees of "glare" from motor vehicle headlights and for different types of road surface. A description of this work and some of the results are included in this bulletin which should be of interest to motorists as well as to those technically interested in the problem of night driving. It should be remembered that the results given can be interpreted as indicating a general trend only. This is evident from the nature of the investigations.

ACKNOWLEDGMENT

The testing and research work herein described was done in the Photometric Laboratory of the Department of Electrical Engineering and under the supervision of that Department.

The author wishes to thank Mr. J. W. Knudson, Jr., who ably assisted in the laboratory tests and was responsible for the early work in the preparation of this bulletin; Mr. Leland L. Antes for preparing the diagrams; Professors J. M. Bryant and J. A. Correll of the Department of Electrical Engineering for their helpful suggestions during the progress of the investigations; and Professor S. P. Finch and Mr. H. R. Thomas of the Bureau of Engineering Research for their assistance in the preparation of this bulletin.

Professor J. A. Correll and Mr. J. W. Knudson, Jr. handled the work of testing the large number of devices which were submitted when the Texas headlight regulations first went into effect. Mr. Leland L. Antes is in charge of this testing work at the present time.

I. MOTOR VEHICLE HEADLIGHT DEVICE TESTING FOR THE STATE HIGHWAY DEPARTMENT AND PROGRESS IN MOTOR VEHICLE HEADLIGHTING

Motor Vehicle Headlight Device Testing.—When the Thirty-ninth Legislature enacted the Texas Automobile Headlight Law, the Photometric Laboratory of the Bureau of Engineering Research was designated as the State agency for determining whether or not the various types of headlight devices complied with the requirements of the Act concerning light intensity and distribution. These requirements are the same as the 1922 Illuminating Engineering Society Specifications which are now in force in states which register approximately 75 per cent of the motor vehicles in the United States. These specifications are generally considered the American standard for the approval of headlight equipment.

After a thorough investigation, by Professor J. M. Bryant of the Department of Electrical Engineering and the author, of headlight testing equipment at the United States Bureau of Standards and the Electrical Testing Laboratories, New York City, special equipment was designed and installed in the University laboratory. Equipment available for use for headlight device testing and other photometric work is as follows:

1. Mounting rack for headlamps.
2. Standard parabolic reflectors and test housings.
3. Sharp-Millar photometer.
4. Weber photometer.
5. Thirty-inch integrating sphere.
6. Eighty-inch integrating sphere.
7. Bureau of Standards calibrated lamps for directional and spherical candlepower.
8. Headlight equipment, previously attested by the Electrical Testing Laboratories, which is used for checking.
9. Horizontal candlepower calibration equipment.

10. Large screen marked with test points.
11. Macbeth Illuminometer.

The 1922 I. E. S. Specifications referred to guarantee to the average driver ample light on the road as a minimum condition and at the same time the minimum amount of glare. These Specifications were produced by engineers foremost in the illuminating engineering field after several years of intensive research. The accompanying diagram (Fig. 1) shows the general plan used in specifying the light

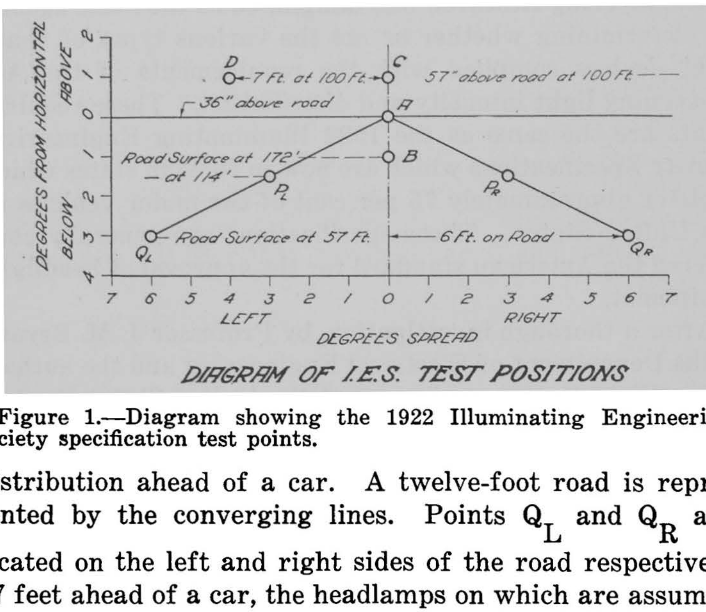


Figure 1.—Diagram showing the 1922 Illuminating Engineering Society specification test points.

distribution ahead of a car. A twelve-foot road is represented by the converging lines. Points Q_L and Q_R are located on the left and right sides of the road respectively 57 feet ahead of a car, the headlamps on which are assumed to be 36 inches above the ground. Points P_L and P_R are similarly located 114 feet ahead, and Point B is at the center of the road 172 feet ahead. These five points are known as "road points," and for them certain minimum intensities are specified, thus assuring ample road light. Point A is located on the horizontal through the headlamp centers and represents the vanishing point of the road. The light that falls on this point is the light that would reach an approaching car quite a distance down the road. This point may also be termed a "road point" since a certain minimum amount of light is specified.

Point C is at the center of the road one degree of arc above the lamp centers. This point is located 57 inches above the road at 100 feet ahead of a car. Point D is one degree of arc above the lamp centers and four degrees to the left of the road center. It is 57 inches above the road and 7 feet to the left at a distance of 100 feet ahead of a car. These last two points are known as "glare points." The maximum light allowable at these points is specified, and represents in each case the maximum allowable light as determined by a large number of drivers. The apparent candlepower specifications for these eight test points are as follows:

Point A. Not less than 1,800 candlepower.

Point B. Not less than 3,600 candlepower, and there shall not be less than 3,600 candlepower at any point on the horizontal line through B, one degree to the left and to the right of B.

Point C. Not more than 2,400 candlepower.

Point D. Not more than 800 candlepower.

Points P_L and P_R. At each of these points and at every point on the line between, not less than 2,500 candlepower.

Points Q_L and Q_R. At each of these points and at every point on the line between them, not less than 1,000 candlepower.

The term "candlepower' as here used means "apparent candlepower." The apparent candlepower at any point is determined by multiplying the illumination in foot-candles at the point by the square of the distance to the light source.

This general method of attacking the problem is logical and effective as shown by the great general improvement in night driving conditions.

The complete list of devices approved by the State Highway Department upon recommendation of the Laboratory is given below.

LENSES

Bausch & Lomb
Bausch & Lomb Star
Benzer Lens, Type A
Broadlight Lens
Dodge Brothers Lens
Dupont Safety Glare Lens
Ford H. Lens
Flintex Lens
Hudson Lens (Ford size)
Johnson Lens
Liberty Lens, Type D
Liberty Lens
Lincoln Projector Lens
Macbeth Lens, Type D (Green Visor)
McKeelite Lens
Monogram Lens
Osgood Lens, Type B 23
Parab-O-Light Lens, Type FW
Patterson Lens
Smith Lens
Spreadlight Lens
Standard Lens
Tips Lens
Tumey Lens

COMPLETE HEADLAMPS

Depress Beam Headlamp
Dual Light Headlamp
E. & J. Type 20 Headlamp
Glolite Headlamp
Guide Ray, Type A Headlamp
Hilco Headlamp
Miro-Tilt Headlamp
Monogram Twin Beam Headlamp
Parabeam Headlamp
Tilt Beam Headlamp
Tilt Ray Headlamp
Twolite Headlamp
Ryan-Lite Headlamp

COMBINATION DEVICE

Pathfinder Device with Spreadlight Lens

MOTORCYCLE DEVICES

Benzer Lens
Monogram Lens
Spreadlight Lens

REFLECTORS

Brown Universal Reflector and Brown Universal Adaptor Reflector
El Camino Reflector and El Camino Adaptor Reflector
Flatlite Reflector and Flatlite Adaptor Reflector ("Standard" only)
Garda Reflector
Hilco Reflector
Paraflector Reflector
Trippe Reflector
Flatlite Courtesy Reflector

While all of the devices in the approved list comply with the standard specifications, they have various characteristics which recommend them to different types of drivers. Some concentrate a large portion of the light quite a distance down the road, such a light being preferred by those inclined to fast driving; others spread the beam more near the car, and, as a result, throw less down the road. This type is preferred by slower drivers and especially by those who drive in mountainous country where narrow, winding roads are encountered. Too frequently a motorist condemns his headlights for giving insufficient light when the real trouble is not in the amount of light, but in its distribution. The variation in the total light output of new 21-candlepower bulbs, now almost universially used in automobile headlamps, is exceedingly small, provided voltage and other conditions are the same. The complaint of the motorist that he has insufficient light must be modified, therefore, by saying that he has insufficient light at the particular places he desires and really needs it for convenience in night driving.

The above list is the result of tests on sixty-five devices, forty-nine of which complied with the requirements. Slight changes in devices by several manufacturers have resulted in nine check tests, each of which proved satisfactory.

The sixteen devices failing to meet the requirements represent approximately 25 per cent of the devices submitted. This demonstrates the protection the State affords its motorists from the flood of worthless devices which would naturally result from the lack of headlight regulations. If there were no regulations, it is not difficult to imagine that the number of worthless devices would far exceed the percentage given above.

A brief analysis of the devices failing to meet requirements should be of interest to the general public. Several of the devices failing were those which had been in use for several years. In fact, some of them were introduced immediately after the acetylene lamps began to give way to electric headlamps. These designs were the result of lack of study of the problem of light projection and distribution. Practically none of these devices is now manufactured. By far the greatest number of those failing may be termed freak devices. Such devices are usually the products of would-be inventors spurred in their work by visions of a great fortune, and in most cases these individuals apparently had never taken time to study the problem they undertook to solve.

Of the sixteen devices that were rejected, four failed to modify the circular beam pattern which results from a parabolic reflector, but decreased the total amount of light; three, similar to the first four in result, absorbed a large portion of the light by introducing metal between the bulb and reflector; seven failed due to poor distribution of light, some of which produced an increased amount of glare at glare points; one failed absolutely to modify the beam; and one absorbed approximately 75 per cent of the amount of light produced. Yet how easy it would have been for some enterprising salesman to convince large numbers of motorists that almost any one of these devices was a great discovery and would provide both more light for driving and "absolutely eliminate all glare." To cement these statements he would guarantee satisfaction or refund the sale price. After an intensive sales campaign such salesmen are usually hurriedly called to another state on business.

Progress in Motor Vehicle Headlighting.—Consideration of the headlight problem shows that it is twofold, the aims being to provide proper road illumination and to reduce glare to a minimum, since it cannot be entirely eliminated. The characteristic point of failure of freak devices is their singleness of purpose; they either decrease glare at the expense of road illumination or obtain increased road illumination with consequent glare increase. The effectiveness of devices which comply with the standard requirements comes in the compromise position of meeting the minimum requirements for good road illumination with the smallest amount of glare. Briefly, in all of the work to improve headlighting conditions the line of attack has been to remove as much light as possible from the region above the horizontal through the lamp centers in order to reduce glare, and to utilize this otherwise misplaced and wasted light on the road. Whatever advance has been made in bettering night driving conditions has come only after a great amount of work in the laboratory and on the road. Hundreds of observers have been used to determine what the average driver desires in amount and distribution of light, and also to determine what beam intensities produce "glare." It is easily seen how important a part the factor of light distribution plays in the solution of the problem; in fact, the success of the standard specifications is due entirely to an understanding of the requirements of light distribution on and above the road.

The manufacturers of headlight equipment are to be commended for their untiring efforts to improve their products along the lines of the standard specifications. All makes of cars now come equipped with approved devices so that no longer do motorists have to worry about purchasing new equipment which complies with standard specifications. The advantages of uniform regulations in all states are both numerous and obvious. Since cross country automobile traveling has become so popular, motorists are demanding uniform regulations, at least in fundamentals. No one relishes changing headlight equipment at every state line.

A great step forward will be taken when the individual motorist realizes that after his car is properly equipped, upon him rests the responsibility of bettering night driving conditions. If such an attitude does not come as a sense of duty, it will probably come as a means of self protection. Light kept out of the glare zone and properly placed on the road assures safety in passing. The approaching driver will not be blinded, and a well illuminated road reduces the glare effect so that both drivers are enabled to see the road. It is difficult to predict what course a blinded driver will follow, and therein lies the cause of a large number of accidents which occur annually, many of which prove fatal.

Despite the recent progress in headlamp construction, the requirements of service are too severe to expect equipment to stay in adjustment over long periods of time without attention. The car owners must realize that just as much attention must be paid to headlight equipment as to other parts of a car requiring servicing. One of the greatest causes of trouble is that bulbs are jarred out of focus. This causes a change (always for the worse) in light distribution from headlamps. Poor voltage conditions will always reduce the amount of avaliable light. Headlamp covers not properly installed are frequently leaky. Water or moist air reaching reflectors will cause rust after a short time.

When covers are loose, lenses often turn so as to spread the light vertically or at an angle rather than horizontally, and in such position cause severe glare. Bulbs in use for long periods sometimes fog or blacken and thus absorb a large portion of the light given off by the filament. Minor collisions are often responsible for bending headlamps backward or to the side enough to decrease road illumination and increase glare. Figures 2 through 5 illustrate some of the points mentioned. In practically every case the car owner is the one that suffers most. It is a simple matter to correct any of these faults, and where adjusting stations are available there is little excuse for failure to care properly for headlight equipment.

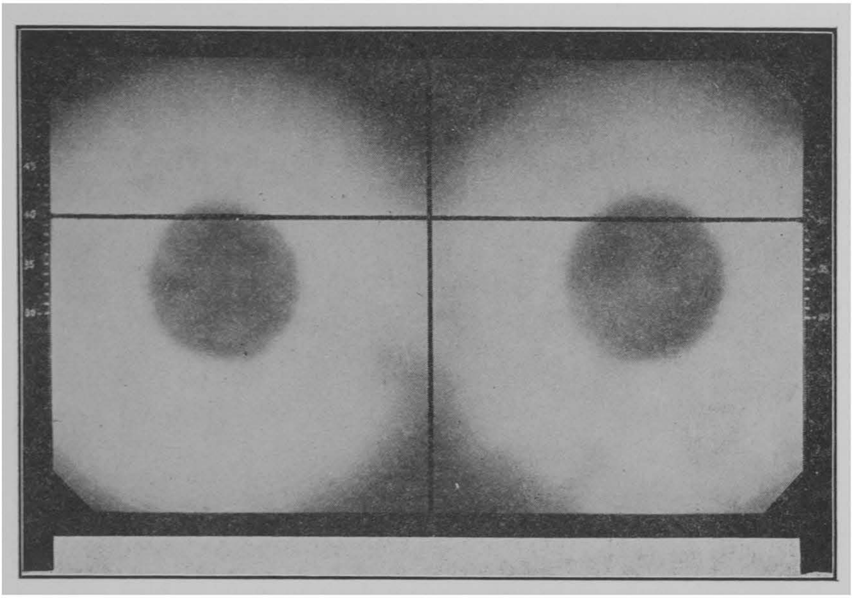


Figure 2.—Beam from bare reflectors with bulbs out of focus. Note the large amount of light wasted above the horizontal line and the large dark areas at the individual beam centers.

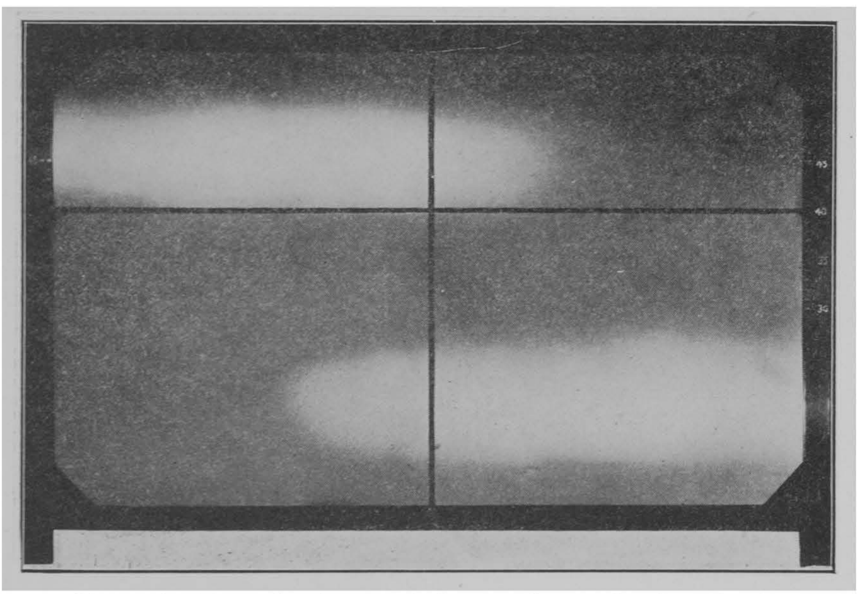


Figure 3.—Example of poor aiming, or the result of a minor collision. Normally the upper edges of both beams should be just below the horizontal line. The individual beams are correct but the headlamps have been bent out of line.

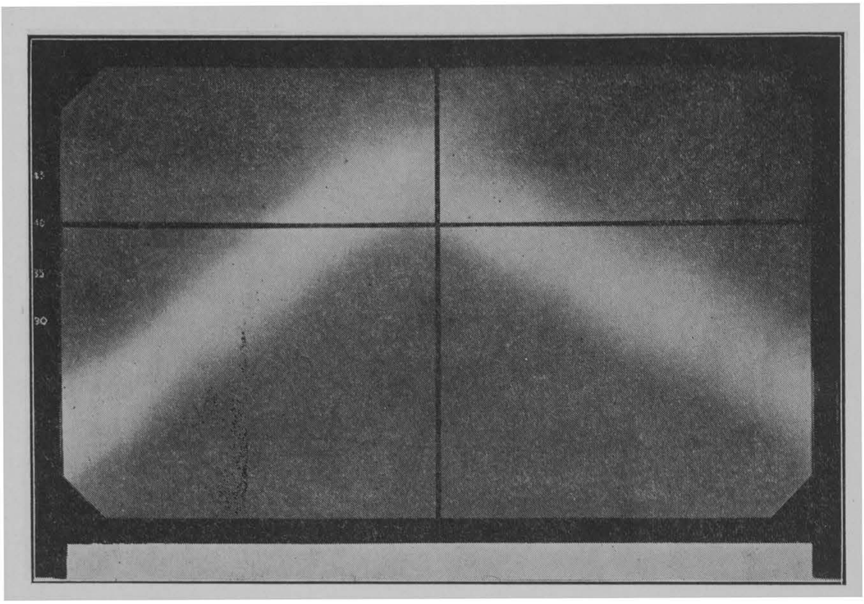


Figure 4.—Example of twisted lenses. This is the result when lenses are jolted out of position or are carelessly installed.

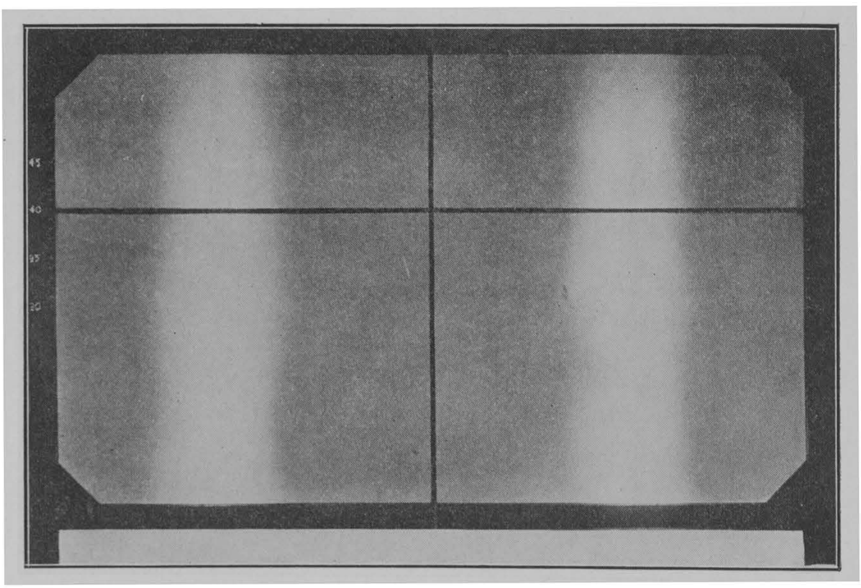


Figure 5.—These lenses have been turned half way around and spread the beam vertically instead of horizontally. Extreme glare may be experienced from these headlamps.

II. GLARE AND ROAD VISIBILITY

Factors Affecting Glare and Objects of This Investigation.—Glare from automobile headlamps has long been the greatest hazard encountered in night driving; road illumination in comparison, after a certain necessary degree is obtained, is of minor importance. Poor road illumination forces caution on the driver at all times. The length of time glare conditions obtain is usually a small per cent of the total time spent in night driving, even during moderate traffic, but such periods hold many dangers since they are frequently periods in which the drivers are unable to see the road.

The severity of these periods depends upon several factors. Glare has been well termed "any brightness within the field of view of such a character as to cause discomfort, annoyance, interference with vision, or eye fatigue." Glare may be attributed to each of several causes individually or to a combination of them. The most important of these are the intrinsic brilliancy of the light source, the total light output, its location in the field of view, its contrast with the immediately adjacent background, and the length of time the source is viewed. Such a list represents a static condition and does not take account of a change of condition. To cover changing conditions therefore the previous status of the eye must be considered, as well as the length of time elapsing during the change, and the change itself. In analyzing glare from automobile headlamps the transient feature is of importance and must be considered. The rapidity with which a car approaches, the brightness of the headlights, and the background contrast will play major rôles in contributing to the effect called "glare." The aggregate effect of these can best be determined by a consideration of the component parts and these parts best studied at their boundary conditions. For the purpose of this investigation "glare" may be considered "blinding glare"—that condition which renders vision impossible so far as seeing the road is concerned.

The first investigation made by this Laboratory into the relation of these factors, as especially applied to night driving conditions, was to determine the effect on vision (ability to see) of headlight brightness and background contrast with the time factor reduced to unimportance as far as approximating actual driving conditions is concerned. The second investigation included the factors of brightness and background contrast, and in addition one phase of the time element. A detailed description of the investigations and results follows:

Brightness and Background Contrast.—It was not intended that this investigation should be exhaustive, but rather that road conditions should be closely approximated and the reactions of a group of individuals obtained. Extreme accuracy would obviously be a waste of time since results would not warrant such care.

The general arrangement of apparatus and observer was as shown in Fig. 6. A twenty-six square foot area (approximately 4 feet by 6 feet 5 inches) of "road" was placed just to the side of an automobile headlamp which consisted of a bulb in a bare reflector. This reflector was one of the

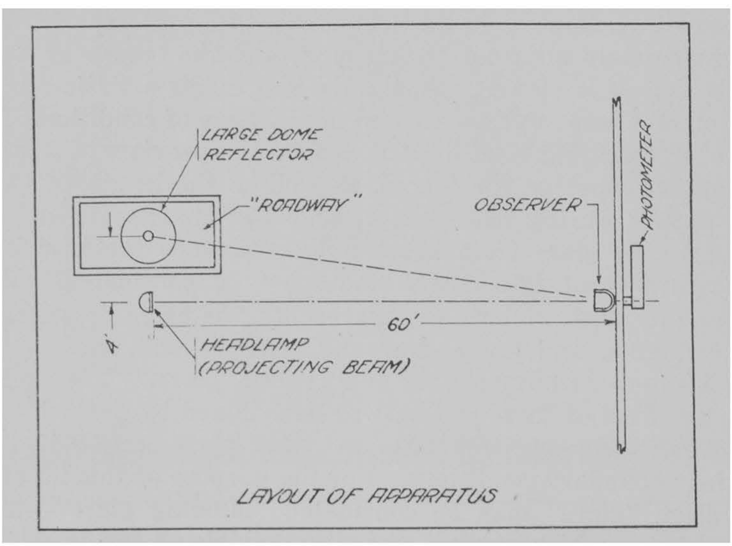


Figure 6.—General arrangement for glare tests.

standard parabolic reflectors used for laboratory testing. The intensity of the beam was variable. A large dome reflector was suspended above the road so as to give a sufficiently uniform illumination over the entire area. The floor area adjoining the patch of road was covered with black cloth of very low reflection factor, thus eliminating any undesired brightness around the test area. The observer was located as shown, with a Sharp-Millar photometer immediately back of his head. The beam was aimed directly at him and so focused as to give a large cross section of uniform intensity at his eyes. His head was guided to the proper position both horizontally and vertically.

The test procedure was to place an observer as shown, to throw upon the road a known illumination, and then gradually to raise the intensity of light in the observer's eyes until the road disappeared from view. The tests were begun at a road illumination of 0.25 foot-candle, and the above procedure repeated for illumination increments of 0.25 foot-candle until a maximum of three foot-candles was reached. Such a test gives the minimum road illumination which must be provided in order for a driver to see the road; that is, the threshold of vision is thus determined for varying conditions of brightness and background contrast. This border condition of course says nothing of how much illumination would be desired for satisfactory vision by the observers under similar conditions. Such data are available, at least for the lower beam intensities.

During the tests, individual points were checked, frequently several times. As a further check is was found possible to duplicate a curve within a very few per cent after a period of six weeks. This was done to show the consistency of the method used in gradually raising the beam intensity. The rate of increasing the beam intensity was slow enough to enable the observers to come to a positive decision as to the point at which the road disappeared. They were allowed short periods of rest between road illumination settings. The observers varied in age from about 18 to 50. Both men and women were used. The curves indicate large differences between individual observers and show why some are "glared" by certain intensities and some are not. It may be of interest to note that the color of a person's eyes seems to be a factor in the amount of glare he can stand.

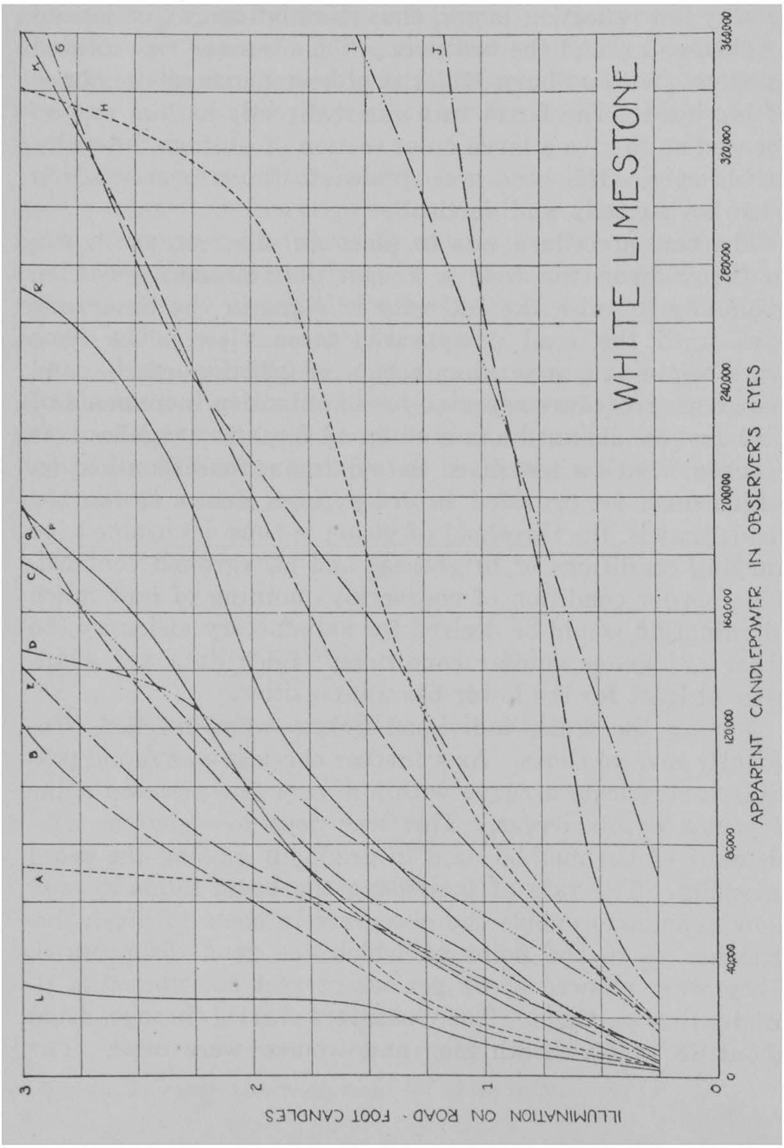


Figure 7.—Curves showing relation of road illumination to beam intensity in observer's eyes at threshold of vision. Crushed limestone road.

Three types of road surface were used in the investigation, black dirt, red gravel, and crushed limestone. The black dirt and crushed limestone represent extremes in the road surface brightness, while the red gravel gives a surface brightness between the two.

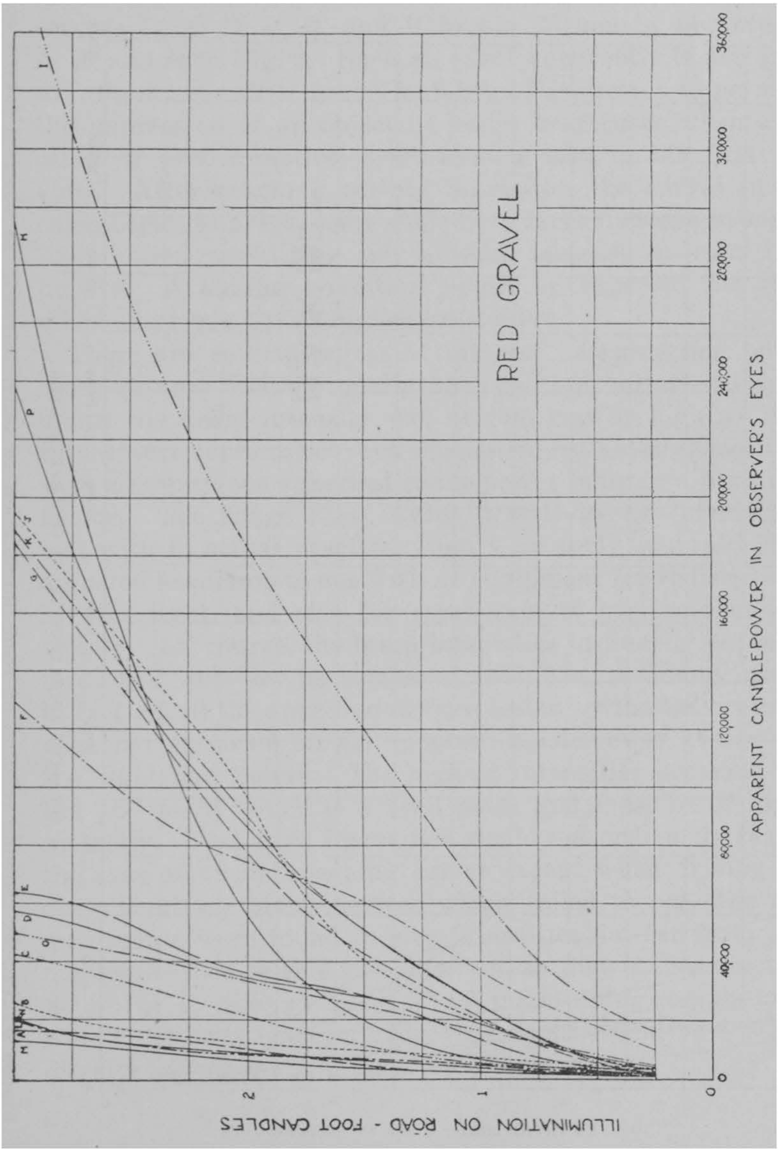


Figure 8.—Curves showing relation of road illumination to beam intensity in observer's eyes at threshold at vision. Red gravel road.

The results are shown in Figs. 7, 8, and 9, each curve representing a single observer. The curves are lettered so as to show the behavior of the various observers for each of the three roads. The apparent candlepower as shown was obtained by multiplying the intensity of illumination at the

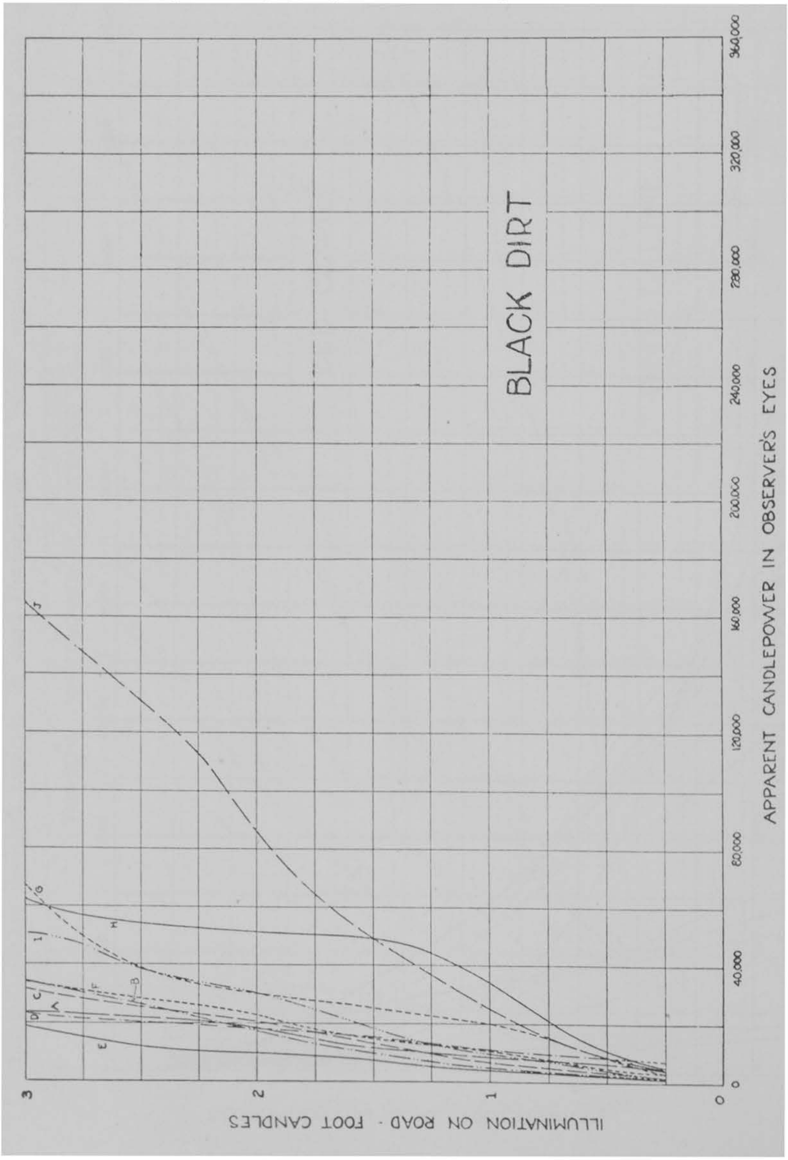


Figure 9.—Curves showing relation of road illumination to beam intensity in observer's eyes at threshold of vision. Black dirt road.

observer's eyes, as measured by the photometer, by the square of the distance to the lamp. The points were plotted for each individual and the curves drawn in smooth.

In this connection attention should be called to a marked tendency toward a saturation effect as exhibited by observers L, A, D, F, R, and H in Fig. 7, and by observers A. F. and H in Fig. 9. Such an effect apparently is not due to fatigue but rather to the inability of the retina to permit the impression of an object of lesser brightness when another of predominating brightness is also in the field of view. After reaching certain intensities the curves indicated began to break, some sharply; a large increase in road illumination permitting only a small increase in beam intensity. A similar condition might be expected for the other observers but at higher intensities.

There are several points of interest in connection with these curves. With properly equipped and adjusted headlamps the beam intensity will seldom run as high as the values were carried, but such intensities are readily obtained with a twenty-one spherical candlepower lamp in a bare reflector. The range used covers practically all intensities met with in actual practice, from a properly equipped and adjusted headlamp to one with no equipment for redistributing the light, and also for conditions of over and under voltage. Of course, the beam intensities ordinarily encountered fall very low as compared with the maximum used; in fact, of all the approved devices tested by the Laboratory none has exceeded 50,000 apparent candlepower at any of the eight test points. The highest intensities occurred at the "B" point which is a road point and must be of high intensity. Such high intensities would not ordinarily reach the eyes of an approaching driver except when driving in hilly country. Many devices which failed to pass the requirements were found to give intensities not far from the maximum used in this investigation, so that if there is any doubt as to the advisability of maintaining regulations which eliminate such hazards, that doubt would be quickly dissolved in view of the results here given.

Using an intensity of 50,000 apparent candlepower as a reference, for the reason given, the data plotted in Fig. 10 were derived from Figs. 7, 8, and 9. This chart shows at once how the ability to see varied with road surface and road illumination. These results were obtained by using only the observers available for all the three road tests. It was not possible to obtain all observers for all three tests.

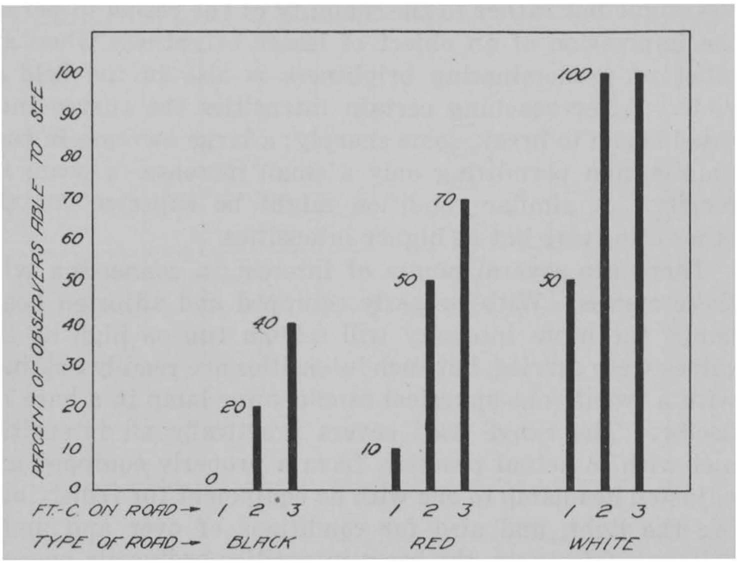


Figure 10.—Showing the effect of road illumination and road surface on the ability to see with 50,000 apparent candlepower in observer's eyes.

At the "D" glare point in the Standard Specifications the apparent candlepower intensity is limited to 800. From the curves for the different road ways it will be seen that at a road illumination of 0.25 foot-candle none of the observers will be unable to see the road, and in most cases the road illumination could be reduced below 0.25 foot-candle and still the observers would be able to see. Such a road illumination is readily obtained fifty or sixty feet ahead of a car.

In order to show how the group of observers responded to the variations in road illumination and beam intensity, Figs. 11, 12, and 13 were derived from the three original sets of curves. The curves are shown with points connected by

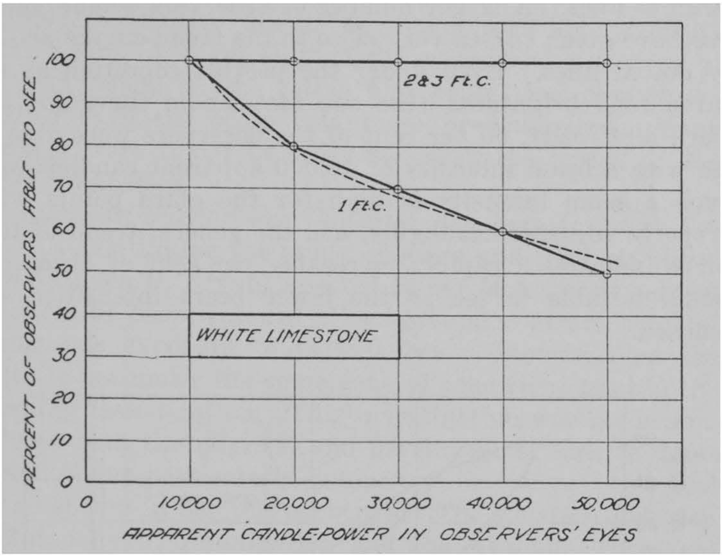
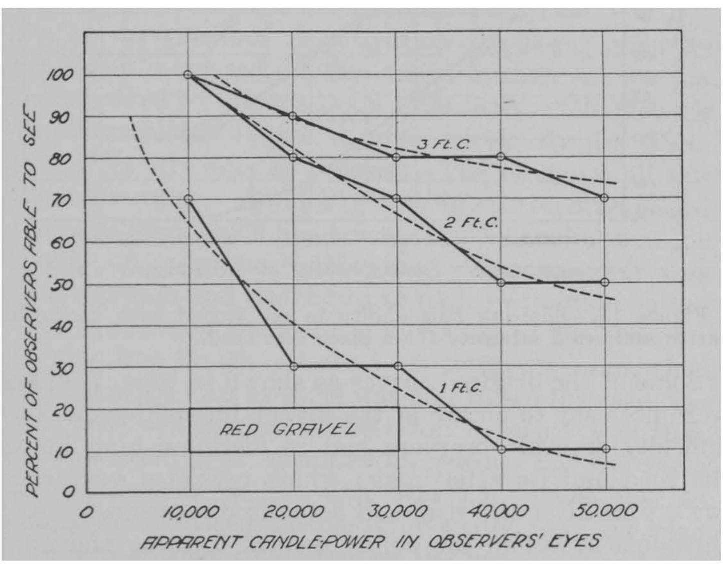


Figure 11.—Showing how ability to see varied with road illumination and beam intensity for a crushed limestone road.



Fifure 12.—Showing how ability to see varied with road illumination and beam intensity for a red gravel road.

straight lines. A larger number of observers would doubtless have given curves very close to the trend-curves shown by dotted lines. Even under the poorest condition as regards road brightness (the one foot-candle curve for the black dirt road), 50 per cent of the observers were able to see with a beam intensity of 10,000 apparent candlepower. Such a beam intensity is high for the glare points with properly adjusted headlights, and the general trend of this curve indicates a rapidly increasing per cent of observers would be able to see as the lower beam intensities are reached.

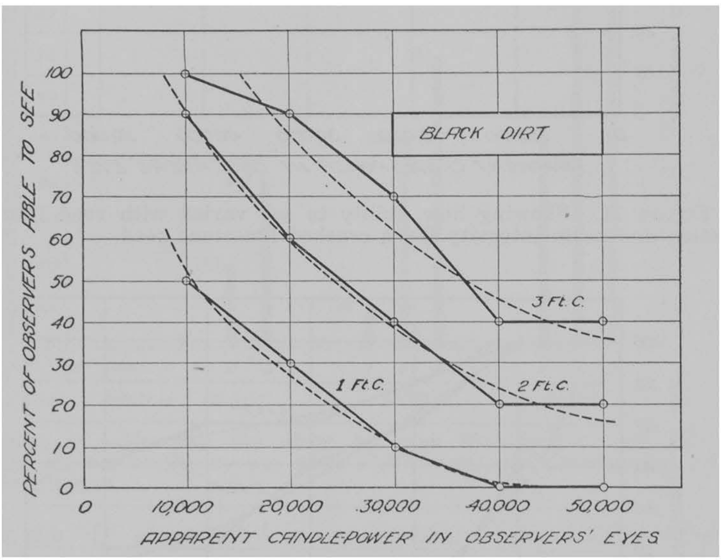


Figure 13.—Showing how ability to see varied with road illumination and beam intensity for a black dirt road.

Some of the original curves as shown in Figs. 7, 8, and 9 were not easy to obtain at the higher intensities due to the difficulty several observers had in distinguishing between the road and its after-image which persisted very clearly for a time after the road had actually disappeared. At the threshold of vision the object seemed to come and go due to the unconscious shifting of the eye in its effort to see the road. If the eye was steady for an instant that portion of the retina upon which the image was focused quickly became less sensitive, due to the predominant high intensity of the beam. A slight shift of the eye caused a shifting of the road image on the retina and again that portion responded until the beam brightness predominated. Many readings were taken in order to check the points at the higher intensities.

Brightness, Background Contrast, and Instantaneous Exposure.—Continuing the study of glare and road visibility, Miss Kathryn H. Bryant selected as her M.A. thesis subject the effect of beam intensity, background contrast, and instantaneous exposure to various beam intensities on the ability to see under the same general conditions used in the preceding investigation. This investigation was made as a study of both the physical and psychological aspects, Miss Bryant being particularly interested in the psychological side as shown in her thesis entitled "The Relation Between the Intensity of Illumination and the Absolute Threshold of Vision" (June, 1927). Valuable information was obtained however from the physical side, and it is this feature of her investigation that is of interest here.

While in the previous investigation the beam intensity was gradually increased, in this case the observer was instantly subjected to various beam intensities while viewing the road illuminated in the manner previously described. The test procedure was as follows: The road was illuminated to a low value. A quick operating shutter was placed over the headlamp which had been previously calibrated for small steps of apparent candlepower. The observer was given a stopwatch and instructed to fix his attention on the road. At the instant the shutter was released the observer pressed the stop watch release. If, with the beam thus thrown instantly in his eyes, he was able to see the road, the time was recorded as zero. The beam intensity was then increased in small predetermined increments and the same procedure followed. If the road was not visible just as the shutter was released, the observer waited until the road appeared and at that time stopped the watch. The beam intensity setting preceding the one requiring fifteen seconds

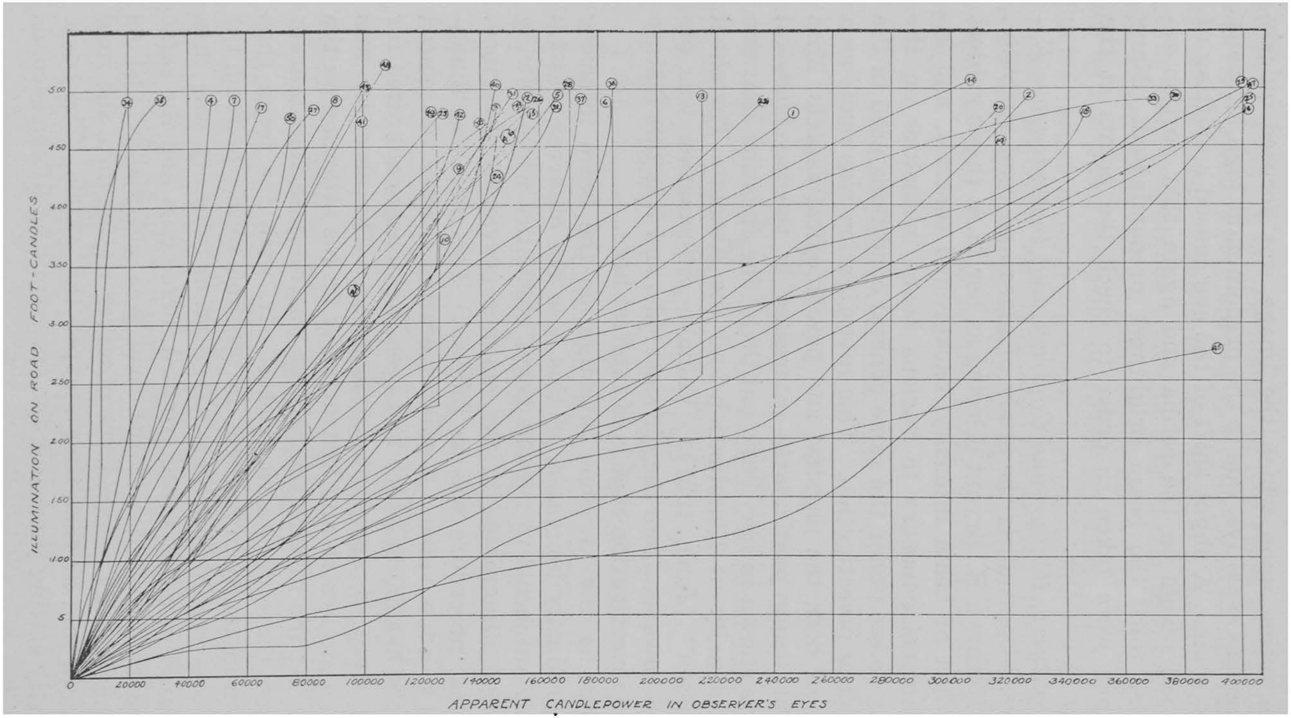


Figure 14.—Curves showing relation of road illumination to beam intensity in observer's eyes at threshold of vision when observers were suddenly subjected to the various beam intensities. Red gravel road.

or more for the road to appear was taken as the threshold point and so recorded. The road illumination was then raised and a similar group of readings taken. The fifteen-second interval chosen is the amount of time necessary for a vehicle moving thirty-five miles an hour to travel 770 feet. This meant that under certain conditions an individual blinded by a car suddenly appearing might drive 770 feet without being able to see the road.

Forty-eight observers were used in this investigation but only one type of road, red gravel. Because of its medium brightness it may be considered representative. The results for the individual observers in this investigation are shown in Fig. 14, the threshold points being plotted and the curves smoothed.

Although the two investigations are not exactly parallel, the results obtained in the second investigation are similar to those obtained in the first. It is interesting to note that in the second test the observers were able to see the road much better for the same beam intensity. The reason for this difference is undoubtedly due to the fact that in the first case the eye was exposed for longer periods of time to the full beam. Also the saturation effect pointed out in the first investigation is still evident in the second, although not to such a great extent.

Fig. 15. shows how the ability to see varied with road illumination if particular beam intensities are chosen as references. These curves were derived from Fig. 14. Two curves are shown, one for 25,000 and one for 50,000 apparent candlepower. Fifty thousand apparent candlepower was chosen for reasons previously stated, and 25,000 was selected for comparison. The shape of these curves is of interest. In the 50,000 apparent candlepower curve there is a decided break at approximately two foot-candles. At this point 75 per cent of the observers were able to see, and a large increase in road illumination intensity was required before the remaining individuals were able to see. This is again evident in the 25,000 apparent candlepower curve, with the break occurring at a lower road illumination. From the 25,000 apparent candlepower curve it is seen that

an illumination of one foot-candle was quite sufficient for approximately 70 per ccnt of the observers, two foot-candles would suffice for 92 per cent, and three foot-candles would enable 98 per cent to see. For an intensity of 50,000 apparent candlepower, more than five foot-candles on the road were required (the actual figure being six or seven) for 100 per cent of the observers to see.

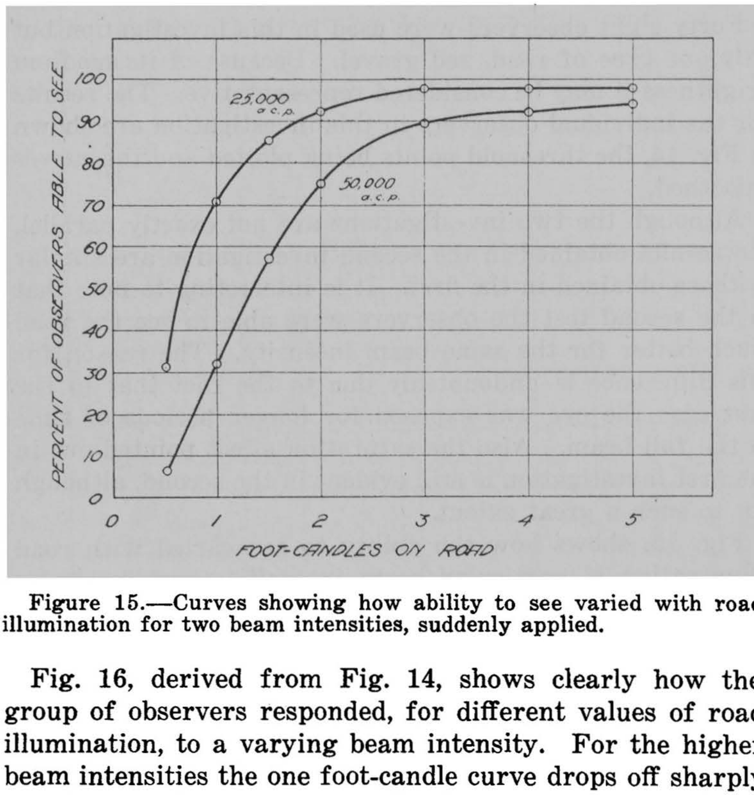


Figure 15.—Curves showing how ability to see varied with road illumination for two beam intensities, suddenly applied.

Fig. 16, derived from Fig. 14, shows clearly how the group of observers responded, for different values of road illumination, to a varying beam intensity. For the higher beam intensities the one foot-candle curve drops off sharply and shows such an illumination level to be inadequate. Under normal driving conditions, however, even a beam intensity of 10,000 apparent candlepower would not often be encountered by a driver, and a reference to Fig. 14 will show that for this beam intensity and an illumination of 0.25 foot-candle, 79 per cent of the observers were able to see.

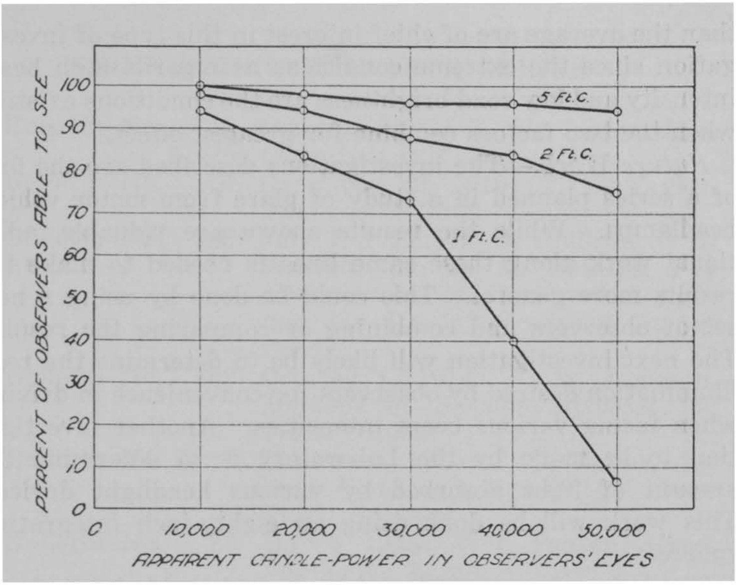


Figure 16.—Curves showing how ability to see varied with beam intensity, suddenly applied, for three values of road illumination.

Application of Results.—The results shown herein may be applied to road illumination obtained from street or highway lighting units or from motor vehicle headlights. It must be remembered that the values of road illumination used were read on the horizontal, and the road area when viewed by the observers appeared less bright than it appeared when viewed from directly above and in line with the incident light, since the road surfaces were not perfect diffusers. If the road surfaces had been illuminated by headlights to the same horizontal illumination values as used in these investigations, the road brightness would have been much greater from the point of view of the observers, due to the fact that they would have been practically in line with the incident beam. The road brightness actually used would therefore not be the maximum produced by a headlight beam. Areas of high road brightness (relative) are small, the lower brightness as used in these investigations being much nearer the average road brightness as found up to 500 feet ahead of a car. Average brightnesses and those lower than the average are of chief interest in this type of investigation since the extreme conditions as regards high beam intensity and low road brightness are the conditions existing when the two factors combine for greatest effect.

Future Work.—The investigations described are the first of a series planned in a study of glare from motor vehicle headlamps. While the results shown are valuable, additional work along these same lines is needed to make the results more general. This could be done by using a new set of observers and combining or comparing the results. The next investigation will likely be to determine the road illumination desired by observers for convenience in driving when facing various beam intensities. Another investigation to be made by the Laboratory is to determine the amount of light absorbed by various headlight devices. This work will be done using an eighty-inch integrating sphere.

The Laboratory is equipped to do various kinds of photometric work, and is ready at all times to be of service to Texas or to individuals who might wish to take advantage of it. Any information regarding the work of the Laboratory will be gladly furnished by the Bureau of Engineering Research or the Department of Electrical Engineering, University of Texas.

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